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Perceptual Tests of the Temporal Properties of a Shuttered LCD Projector

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Abstract

Perceptual motion blur was studied in imagery presented on an LCD projector equipped with a mechanical shutter to reduce pixel hold-time. Perceptual measures of image blur were obtained with both a simple test stimulus, as well as real-world imagery. Both were found to correlate well with the measured pixel hold-time.

1. Introduction

Liquid-crystal displays (LCDs) have higher spatial resolution than the CRT projectors that are typically used in large field-of-view flight simulators [1]. However, a major limitation of LCDs, particularly for dynamic air combat simulation and training, is their temporal response, which often results in the blurring of moving images. The limited temporal response of LCDs is a consequence of two characteristics: 1) slow onset and offset times, and 2) the sample and hold property related to both the design of the LCD driver circuitry and the LCD itself [2]. It was originally believed that moving-image blur was due to the long onset and offset times, often longer than the frame duration, typical of LCDs. However, the onset and offset times of LCDs have been reduced significantly over the past ten years. The motion blur most noticeable in LCD displays today is due to observers' eyes moving past what are effectively stationary objects – a pixel or group of pixels that remain illuminated for the full duration of the video frame.

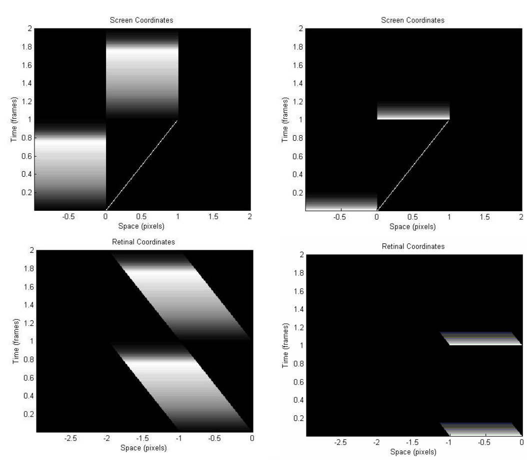

Figure 1. Upper: pixel position vs. time (left: LCD, right: CRT). Lower: pixel position in retinal coordinates as the eye tracks one motion speed (left: LCD, right: CRT).

Figure 1 illustrates how spatial blur is produced by tracking a moving object. The top row of Figure 1 shows space-time representations of a display showing a pixel moving at a speed of 1 pixel per frame. The diagonal line depicts the point of fixation as the eye tracks the moving pixel. During a frame interval, the fixation point leads the stationary pixel causing the image of the pixel to shift on the retina. The space time representation of the stimulus relative to the fixation point is shown in the bottom row of Figure 1.

An estimate of spatial blur can be computed by integrating along the time dimension. Figure 2 shows spatial blur profiles for the LCD and CRT examples. It can be seen that the spatial blur profile of the LCD is shifted and broadened relative to the CRT profile. The spatial blur profile is also broadened when the speed of the moving pixel is increased. This observation provides the basis for our behavioral studies which will be discussed below.

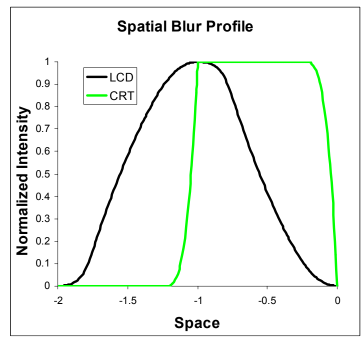

Figure 2. Spatial blur profile for LCD and CRT.

Several techniques have been suggested for improving the temporal response of LCD displays. For instance, modified LCD driving methods [3], intermittent illumination [4], and video processing [5]. In addition, simply doubling the refresh rate may also improve image quality [4]. However, a more effective solution for reducing moving image smear may be to simply reduce the hold-time of pixel activation to less than that of a full frame. However, selecting a reduced pixel hold-time will have to be traded-off against loss of luminance.

A technique for assessing the temporal properties of visual display devices has been previously described [6]. That technique used a simple test stimulus and a direct perceptual test of image blur. Image quality, however, can be affected by factors in addition to image blur, and these factors, as well as their relative contributions to image quality may be expected to depend on various spatial and temporal factors. The spatial factors include image complexity and homogeneity, and the temporal factors are associated with either observer or object motion.

Moving image quality is an important issue for realistic simulation, particularly for dynamic air combat simulation, and the Air Force is therefore interested in techniques assessing display temporal characteristics. Current liquid crystal display technologies are lacking in moving image quality and are not suitable for dynamic air combat simulation. The Air Force is actively investigating methods of improving moving image quality in LCD type displays. In the present study, we have evaluated an LCD projector whose temporal properties have been modified by the use of a rotating shutter that effectively reduces pixel hold-time. The evaluation procedure included measurement

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of the temporal course of the light output of the projector, and, additionally, two perceptual tests for assessing the temporal properties of visual displays. The first perceptual test, described previously [6], consists of a pair of lines moving at various speeds and contrasts. The second perceptual test is an attempt to extend display evaluation to more realistic viewing conditions. In this case imagery representative of an Air Force simulation and training environment was used. We also present the results of a relatively simple model in an effort to predict the perceived blur of moving imagery based on the temporal characteristics of the display system.

2. Methods

2.1. Display Characterization

The display device was an experimental LCD projector (1600x1200 pixels) that employed a rotating shutter to reduce pixel hold-time. The shutter was synchronized with the activation of the blue and green LCD panels. Because the activation of the red LCD panel was reversed relative to the blue and green, and therefore not synchronized with the shutter, only the blue and green imagery were projected onto the screen. An LCD over-driving technique was also employed throughout the display characterization and Experiments 1 and 2.

Display spatial resolution was characterized using procedures adopted from accepted measurement standards [7, 8]. Display temporal response was measured for both the LCD (shutter and no-shutter) and a CRT projector using a photodiode-based circuit and an oscilloscope. The photodiode was directed at a 30 Hz flashing square generated by our test program. A Fluke ScopeMeter was used to record the photodiode response. Brightness and contrast measures and gamma measures were also obtained for shutter/no-shutter.

2.2 Experiment 1

In Experiment 1, we used a simple test stimulus consisting of a pair of moving vertical lines in order to obtain an estimate of the image blur associated with moving objects displayed using the LCD projector. The projector was evaluated in standard mode as well as with the shutter mechanism described above. These two conditions will be referred to simply as no-shutter and shutter, respectively. Four experienced pilots participated in this experiment. The moving line-pairs varied in speed (100 to 800 pixels/second), direction (left to right/right to left), and contrast. Observers simply selected a separation between the two lines such that they did not perceive a gap between the two lines. A larger selected separation indicated greater perceived blur.

2.3 Experiment 2

In this experiment, six experienced pilots were asked to rate the acceptability of the experimental LCD projector for simulation and training applications. The pilots were instructed to actively fly through a terrain database identical to that used for Air Force training (Nellis AFB). An F-16 flight simulator was used. The same flight path and maneuvers were conducted with and without the experimental shuttering mechanism. Following each session, pilots answered several questions regarding image quality and perceived blur of the terrain imagery as well as the air and ground target models.

3. Results

3.1 Display Characterization

The results of the brightness and contrast measures on the LCD projector showed that the use of the shuttering mechanism reduced luminance by approximately 40% (see Figure 3). For experiments 1 and 2, the luminance of the no-shutter condition was therefore reduced approximately 40% using a neutral density filter. Based on the spatial resolution measurement, the number of resolvable lines were 1723x2496 and 1600x2592 for shutter and no-shutter, respectively.

Temporal response data for the LCD projector (Shutter and No-shutter) and a CRT projector are shown in Figure 4. When the shuttering mechanism was activated the duration of pixel illumination was reduced, on average, by about 3 msec (at 1/e amplitude), or approximately 30%.

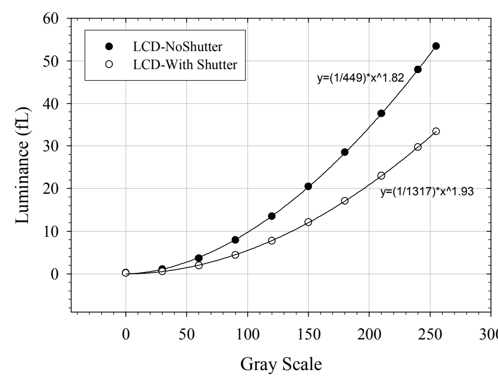

Figure 3. Display gamma with/without shutter.

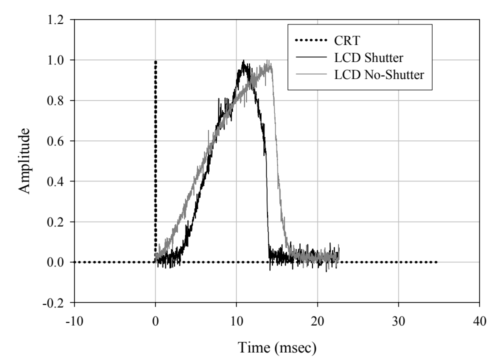

Figure 4. Temporal response of the LCD projector for both shutter conditions. CRT temporal response data are shown for comparison.

3.2 Experiment 1

Averaged perceptual data for the shutter and no-shutter conditions are shown in Figure 5. Pixel hold-time was reduced from about 11.3 to 8.3 msec (at 1/e amplitude) by the use of the shutter (as shown in Figure 4). This difference resulted in an approximately 50% reduction of perceived blur, on average, for the two fastest rates of motion of the moving line-pairs (Figure 5). The increase in speed clearly increased perceived blur [$F(3, 9) = 21.3$, $p < 0.001$] for both with/without shutter. An ANOVA also indicated that the overall decrease in perceived blur with the use of the shutter was significant [$F(1, 3) = 88.9$; $p < 0.01$].

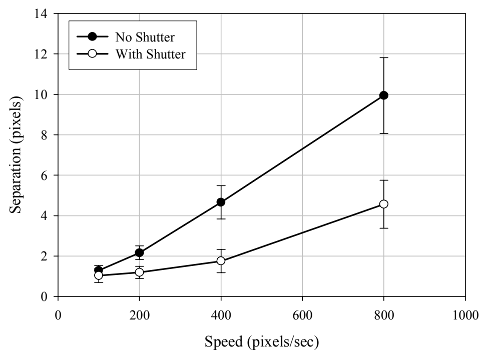

Figure 5. Experiment 1 results: average separation distance selected by observers as moving line pair speed increases.

3.3 Experiment 2

In the shutter condition all observers noted that perceived blur was reduced. All observers also indicated that they preferred viewing the shutter condition. Responses to the questionnaire items were scored and averaged.

Figure 6 shows the averaged response for the questionnaire item "Rate the overall degree of blur" after viewing the flight simulation imagery for shutter and no-shutter. An ANOVA indicated that the difference in rating scores between the two conditions was significant [$F(1,5) = 10.8$, $p < 0.05$]. Several pilots noted in their comments that the blurring was still evident when the shuttering mechanism was used but that it seemed to "recover faster" during aggressive maneuvering and required more rapid rolls and maneuvering to become noticeable. Pilots were more likely to agree that the blurring would inhibit training without the shuttering mechanism compared to with the shuttering mechanism. The results of the subjective evaluation were highly correlated with the objective moving line-pair test in Experiment 1 ($r = 0.93$, $p < 0.01$).

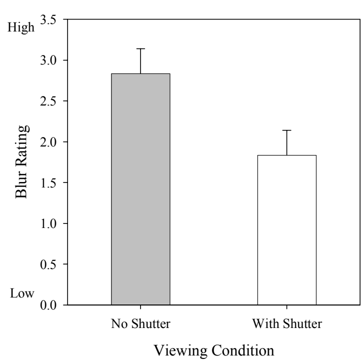

Figure 6. Experiment 2 result: average response to one questionnaire item after viewing flight simulation imagery.

4. Predicted Perceived Blur

A simple model was devised in an effort to predict the perceived blur indicated by subjects in Experiment 1. The normalized temporal profiles for the no-shutter and shutter conditions (see Figure 4) were used to generate retinal coordinate images (e.g. Figure 1. bottom row) for a range of line speeds. We then integrated along the time dimension to produce spatial blur profiles. The results are shown in Figure 7. The simulation results are qualitatively similar to the experimental results - the spread of the blur profiles increases with line speed and the spread of the profiles from the shuttered condition are less than those from the no-shutter condition at all speeds.

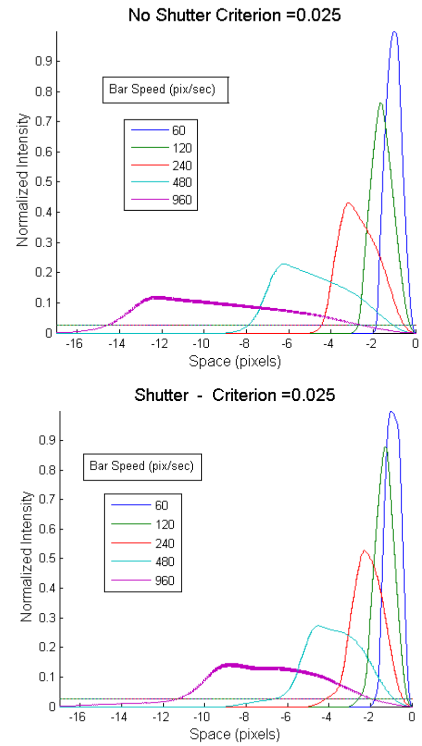

Figure 7. Spatial blur profiles based on temporal profiles shown in Figure 4. Above: No-shutter. Below: Shutter.

In order to make quantitative predictions of the experimental data, we measured the width of the spatial blur profiles at a criterion height. Because the experimental data reported the gap and not the offset between the moving lines (i.e. a non-blurred stimulus would result in a gap of 0) we set the model gap size to the blur profile width –1.0. The criterion height was adjusted to match the no-shutter prediction with the no-shutter experimental data. Figure 8 shows the comparison between predicted blur and the results of Experiment 1. The model prediction for a criterion of 0.025 is depicted by the solid line in Figure 8. When the same criterion was used to estimate the blur in the shutter condition (Figure 8 dashed line) the model produced offsets that were larger than the behavioral measurements.

5. Discussion

The present data show, for an LCD projector, that the results of a previously described direct test of perceptual blur correspond well with measurements of the time that light is present during each video frame. In addition, the results indicate that a relatively small change in the time course of LCD light output can significantly reduce perceived blur. If this result can be confirmed for other projectors, it may be possible to improve temporal performance with only a minimal reduction in light output. The larger than expected decrease in perceived blur was not accounted for in the simple model we developed to predict motion blur.

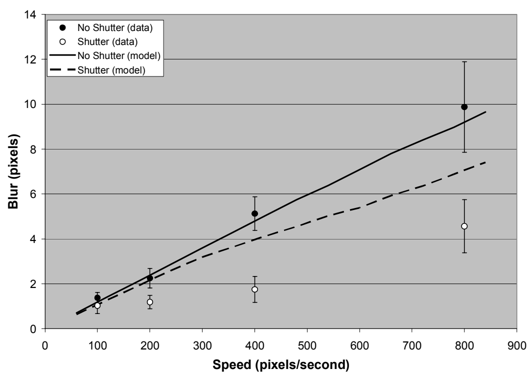

Figure 8. Perceived blur indicated by observers (data) compared to blur predicted by our simple model.

The model used a single criterion height to quantify the width of the spatial blur profile. Examination of Figure 7 shows that the right and left edge of the spatial blur profiles have different slopes particularly at high speeds. Perhaps two criterion heights, one to localize the left edge and one to localize the right edge would result in better agreement between the model and the data. In addition, while the model provides a reasonable description of the retinal image under perfect tracking conditions it makes no attempt to account for changes in the image due to imperfect tracking. Finally and perhaps most importantly, the model does not try to estimate how the retinal image is represented in the visual system. For example, a nonlinear intensity response function and contrast gain control would markedly change the internal representation of the retinal image.

The moving line-pair test is, in some ways, similar to another method of assessing display temporal quality - the motion picture response time, or MPRT [9, 10, 11]. With both of these methods the blurring of moving imagery can be assessed for a variety of motion speeds and contrast levels. However, with the method described in Experiment 1, objective measurement of image blur is obtained from human observers, thus in some applications potentially reducing the need for a high speed pursuit CCD camera.

Someya [12] found that MPRT results correlated quite well with observer estimates of perceived blur using a method of adjustment task in which observers attempted to match the appearance of blur on a standard LCD to that displayed on a second CRT display. The moving line-pair task is similar but has the advantage that estimates of blur can be obtained from a single display of interest. It would be worthwhile to compare the blur predicted by the MPRT and various other methods including those described here. If perceived blur depends on factors other than motion speed and pixel hold-time, such as the human visual system representation of the retinal image then the MPRT may also overestimate perceived blur when methods of reducing pixel hold-time are employed.

6. Conclusion

The results of a simple, direct test of perceptual blur were found to be consistent with a second perceptual test based on how real-world, flight-simulator imagery appeared to experienced fighter pilots. The present data support the utility of perceptual tests in simulator display evaluations, and suggest that assessments of the quality of displayed imagery are useful in the context of visual simulation.

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